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SENSORY PERCETPION OF SURFACES QUALITY
INDUSTRIAL PRACTICES AND PROSPECTS

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ABSTRACT

In this paper we carry out a critical analysis of the industrial practices used by the partner firms to control a product's aspect. The group of partners represents many different sectors of activity such as: luxury goods industry, furniture industry, medical equipment (prosthesis), plastic injection and watch-making industry. These practices deal with the identification of aspect anomalies, the evaluation of anomalies severity as well as the decisions about the product's conformity. We will show that current practices do not allow us to decrease the variability of the results frequently observed, because the subjectivity often associated with this kind of control is not eliminated using such methods. In every sector studied, we find the same dissatisfaction about the results obtained.
We will then present our approach to sharply decrease this variability. This approach, tested in a famous Swiss watch-making company, is based on sensory analysis concepts. This approach is original due to the breakdown of the visual-control process into three sub-processes: the detection of aspect anomalies, the evaluation of those anomalies and the conformity decision. This approach also includes a metrological organisation and some tools which allow us to measure the efficiency reached. The paper will show how our approach succeeds in meeting the different aims of the partner company group and proposes an initial structured approach for a generic metrological organisation adapted to control the variability during the surface quality control by humans.

1. INTRODUCTION

Product quality is usually defined as "the characteristics which allow the implicit and expressed needs to be satisfied" [1]. So, the level of product quality strongly depends on its functional skills, its reliability, and its cost or even on the quality of the associated services (after-sales, guarantee…). However, the quality also depends on the way the customer perceives the product [2]. This perceived quality, *which is evaluated by visual, tactile, acoustic, gustatory and olfactory impressions* [3], plays a very important role in order to reach the best quality of a product proposing more than functional efficient products but also esthetic efficient products. In the same time K.Forslund [4] shows the effect of geometric variation on perceived quality. The visual robustness of geometrical variations is so presented as a side of perceived quality.

Our work deals with one criterion of the perceived quality: the aspect of product's surfaces. This study is part of a European research program « INTERREG » putting together two laboratories from the two universities, university of Savoy and the Lausanne federal polytechnic school

(EPFL), two institutional partners: CTDEC and CETEHOR and six industrial firms. The aim of this project is to create methodological support and the tools needed to improve the visual control of high added value products.
First of all, in this paper we carry out a critical analysis of the industrial practices used by the partner firms to control product aspect. The group of partners represents many different sectors of activity such as: luxury goods industry, furniture industry, medical equipment (prosthesis), plastic injection and watch-making industry. We will then present the tools we propose to answer to those problematic.

2. INDUSTRIAL PROBLEMATICS

This diversity shows the universality of the perceived quality problematic. However the objectives of aspect-control differ depending on the product specificities and its market positioning. Indeed, for the luxury goods industry and furniture industry the way to reach a quasi perfect esthetic imposes its own criterion. For the plastic products, the aspect control permits to show out the deviance of the fabrication process in order to guarantee the product's functionalities. And in the medical field (prosthesis fabrication) impacting a lot the patient life, the aspect quality is the esthetic way to transmit the global quality level of the whole product (resistance, functionality, reliability). Those different faces of aspect-control provide specifics problems. Despite of this diversity, all the partner firms meet behind the same problematic: how to build a sensory evaluation process which is repeatable, reproducible and stable in time.

The subjectivity of the Human judgment in terms of esthetic and perception introduce variance in the control results. The problem of repeatability and reproducibility is due, for the main part to this variability [5]. This variability can be explained by the variance of the measure conditions, of the semantics and cognitive process of perception between controllers [6, 7, 8] and the perception and judgement performances of one controller at a different time, due to his emotion or his tiredness [9].

More than punctual disagreement about the product's conformity, this omnipresent subjectivity induces difficulties to maintain a precise quality level. Experience shows that controllers tend to be more and more strict, which increase the quality level.

3. PRACTICES ASSESMENT

Due to the lack of recognized universal approaches, each firm set up special practices in order to solve the visual-aspect-control problems. But in all firms, the direction committees are not satisfied by the control efficiency and the controllers complains about how hard it is to respond to the task. Here is the list of the most heard complaints:

Table 1: Complaints list

Too many defects are not detected Not stable quality level in time	Very long learning period Different judgment depending on controllers
Unjustified rejects	Communication difficulties in the supply chain

Decision taking problems	One unique person as referent

We noticed that all those complaints are coming from the repeatability and reproducibility problem:

The Repeatability is defined as the ability of the appraiser to "repeat" his/her decisions (agree with him/herself). Calculated as (# agreements / # parts inspected)

And the Reproducibility: Ability of all the appraisers as a whole to "repeat" their decisions among them. Calculated as (# agreements among all appraisers / # parts inspected)

The reproducibility result is made of three components:

Concordance: (# parts that agree with the standard / # parts inspected).

False Alarms: (# parts classified as "defective" when in fact is perfect / # of perfect parts)

Wrong Classification: (# parts classified as "perfect" when in fact is defective / # of defective parts)

In this paper we want to make the list of the most significant practices we meat in the different firms. And we propose an analysis of theirs relevence and efficiency. This repeatability and reproducibility problem is one of the most important points. In this paper we also want to highlight the origins of this problem.

3.1. A rich and varied vocabulary

To harmonize judgements, the use of a common and shared vocabulary is very important. However we noticed that the controllers in the partner firms use too many terms to describe the different kind of anomalies (from few dozen till one hundred fifty terms). Moreover the terms used, often mix the nature, the causes or even the consequences of the anomaly. The table 2 groups few example of terms or expression used in the firms:

Table 2: exemple de descripteurs rencontrés au sein des entreprises

Deformation, blur, stripe, bubble, sandpaper traces	Run out welding, scraping, sanding, laser tackles	Aspect, brightness, engraving, defects, painting drop

This fuzzy about the anomaly description is, once again source of variability in anomaly judgement. [10, 11]

Some sensory analysis method named “free choice profiling” does not impose any constraints concerning the terms to be used: « descriptors » [12]. Those methods are easier to set up but provide a judgement more personal (no common criterion) and subjective (no references) without any justification.

In the case of visual-aspect-control we try to evaluate and organize the sensory perceptions to give a shared judgement comparing to common criterion (even if they are not the controller’s criterion). That is why using the conventional profiling method (finite numbers of descriptors) permit to reduce judgements variability, getting easier the anomaly description and categorization task insuring a good communication between controllers. But the efficiency of this method comes from the good choice of descriptors respecting some conditions of pertinence, independence, exhaustiveness and discrimination [13].

One important objective of this study is to evaluate the possibility of building a generic descriptor list which could correspond to all fields, to be used by all our industrial partners. In her work with a well-known Swiss watch maker firm, A.S.Guerra proposed a short-list of four descriptors respecting the previous named characteristics [5].

3.2. Use of anomaly panoply

As an answer to the quality level stability, and judgement reproducibility, the firms had to keep in memory all the anomalies detected and the conformity judgement associated. This wish leads the firms to build a whole database named “panoply”. Those databases illustrate each anomaly by a picture or a real product having this anomaly. The main advantage of this tool is the knowledge capitalization of all anomalies within a firm depending on processes and products. That permits to set up easily formation programs, or bring them a lot more efficient and to compare the nature of anomalies meat from a firm to another depending on theirs activities.

On the other hand building such panoply is corresponding to make the list of the possible spelling errors. We thus realize how width could be those panoplies which sometimes gather hundreds of illustrations (pictures or products). Moreover an anomaly could have different impact according to his location on the product, so several pictures are necessary to define the conformity level.

Panoplies represent the reference of the expected quality level and is often used as comparison tool to evaluate the aspect quality. Indeed in some firms the panoplies stand in the working station, it permits the controllers to compare, treat and provide a conformity opinion. But it is very difficult to compare anomalies with different intensity (deeper, longer, larger…), observed on different product (colour, shape, material…). And thinking to build exhaustive panoplies illustrating all intensity of all anomalies on every kind of product is just amazing because the panoplies are product oriented whereas they should be an illustration of the firm’s quality level. But even the firms don’t have such a quality level standard, it has to be defined, created and shared.

3.3. Evaluation criterion and decision process

In addition to the anomaly detection problems, evaluation and decision steps could be source of variability and conflict. Every firm has different way to take care of this point.

The firms from the luxury industry have more sensibility and experience in visual control than others as furniture industry firms for example. And the esthetic specifications impose to treat smaller anomalies. The size of luxury product anomalies makes the comparison of visual-impact harder and it becomes hard to judge the conformity of the product. So in this kind of industry, panoplies are used as a comparison-evaluation tool which allows no to formalize the criterion based on visual perception. This method is available because of the experience of the controllers and sensitivity about visual quality of products.

In the firms more industrial, with less qualified employees, more automated machines and faster production rhythm; the evaluation can not be based on people experience. Those employees from the "hyper-industrial" firms are generally less sensitive and formed to product quality and visual control. Those conditions increase the anomaly evaluation difficulties. The binary criterion ("I see/ I don't see") shortcuts the evaluation task. The decision thus depends directly on the control conditions (light orientation, detection distance, time…). By using this criterion, control the environment becomes mandatory.

3.4. visual control process formalization

In order to transmit the visual-control instructions, the firms created the "control-procedures" which often gather the dimensional and aspects specifications of the product. Here we deal with the part of those "control-procedures" specifying the visual-aspect-control.

Concretely this is a paper document specifying the firm requirement and guides the controller by listing the different kind of anomaly. The tolerance is often specified by giving the allowed number of non acceptable anomalies on the product. These documents also give the control frequency and the maximum number of defective products in case of batch control. The accuracy and relevance of those documents can vary a lot from a firm to another.

As evaluation criterion, the control-procedure mentions the different kind of anomalies to detect, through the descriptors defined. On the other hand, no anomaly quantification systems are set up, and we mainly noticed two different decisions making process:

The worst case: no rules are defined and the controller, depending on his own perception, is in charge to judge the visual impact of the anomaly and provide an acceptance decision referring to the products in the panoply.

The second significant practice we noticed is to define a simple rule about the visual impact of the anomaly. This rule is named "I see / I do not see". The principle is to define all conditions of the control and cancelled the evaluation step. So respecting those observing conditions, if I see an anomaly, it is considered as a defect and the product is classified as non acceptable. In one of the partners, the control conditions are based on using conditions (location, orientation, illumination, distance…). This approach tries to bring the controller closer to the customer perception, but the diversity of using conditions makes the judgment no representative of the visual impact of a anomaly on the customer himself.

By analysing the control-procedures used in every firm, we noticed that they always define « what » to control whereas they should define "how" to control by specifying a standard on the evaluation criterion and describe and impose the environment conditions of the control. Mastering the detection process will permit to guarantee the control exhaustiveness and permit to insure the access to the necessary information for the evaluation or decision step.

A detailed analysis of the Ishikawa diagram applied to visual-control permit to highlight the visual-control most influent factors. We could also separate the factors in two categories:

influencing the detection step or the evaluation step. Even if several factors are easy to control, a lot depends on the product, the material, the process or even on the firm organisation. The following table gathers some of the most influent factors:

Table 3: most influent factors from Ishikawa diagram

Material	Colour / size, product shape / product position in final assembly / completion, texture (shiny, dully, rough, wet, soft…)
Man Power	Vision accuracy / controller's mental and physical shape / instruction and anomaly interpretation / knowledge of the product
Means	Products handling
Method	Knowledge of fabrication process / production pace / complementary task
Mother nature	Illumination (intensity, orientation and dazzling) / work station ergonomics / noise / comfort of work /

Finally we noticed that control-procedures mix three different concepts of visual-control: the anomaly detection, anomaly evaluation and acceptance decision. The decision rule previously mentioned "I see/I don't see" translates this confusion between the three appraise. A.S.Guerra [5] shows how necessary it is to separate those three appraises [5], we will detail this point in the next chapter of this paper.

3.5. Tool aided detection

As we just said, visual-control holds in three distinct steps: detection – evaluation – decision. The evaluation step is often absent in the visual-control process and the detection and decision step are confused. The anomalies detection problem is often identified by the firms, they thus set up some tools to help controllers to detect. The two factors mainly identified by are the anomaly's size and the light used during the control.

Enlargement tool

The norm concerning the watch making industry [14] specifies to control the products with the normal vision (without enlargement tools). In spite of this norm, several firms propose or impose to use binocular or flunks to improve controller's detection skills. In some cases those tools can be useful or even necessary.

Some products may have very small dimensions and a lot of details, even smaller. For example the case of plastic injection products with very small holes: diameter less than one millimetre. That makes the control harder and extremely tiring for the eyes.

The second case concerns the size of the anomaly whereas the size of the product. For example in the luxury industry, the product tends to perfection. This search of perfection induces the detection of the smallest anomaly (even if it is acceptable). The enlargement tools permit to detect every anomaly, and thus permit to set up a performing evaluation step.

The light

Once again the norm [14] gives some recommendations about the illumination of the work station. It recommended in particular using an 800 lux illumination source. But this norm contains no specifications about more important points as the position and the orientation of the light source(s).

The experience shows that defining the light intensity is not enough to insure a good detection. To decrease the variability of the control and make sure the work conditions are comfortable, specify the intensity, position and orientation of the light is mandatory. A.S.Guerra shows impacts of light orientation on anomaly detection and perception [5]. The wrong practices within the firms are due to the lack of communication about this information

3.6. Practices conclustion

The most important points:

every firm developed its own tools depending on its own problematic

no specification of the visual-control task, and conditions

confusion of the three concepts: detection, evaluation, decision (in every firm)

many subjective tools: panoply

The work with the partners firms shows the variability of the practices to satisfy the visual-control. This variability is due to the product produced, which impose very different fabrication processes, production organisation and different level on esthetic and aspect properties specifications. Thus the lack of recommendation, references and exchange on this subject, each firm acquired its own experience. That explains the variability between the partner firms.

Within a firm the variability can be explain by product diversity, especially: size, colour and shape. But it is mainly due to the freedom granted to controllers. This freedom in the task comes from the lack of definition, specification, formalisation and recommendation about visual-control. Thus every controller proceed by his own way, which could be different from a day to another depending on the mood, the place, the time of the day, the motivation, the attention. Once again, this is the reputability problem. The impossibility to set up a reproducible control comes from the difficulty to share the same criterion of evaluation and control conditions [15].

4. A STRUCTURED APPROACHE

The Human subjectivity is the main source of variability in the visual control task. The food industry is used to set up sensory tests thanks to the sensory analysis method. Even if the industrial problematic and application fields are different, those sensory analysis method permits to reduce the variability in a product evaluation by human senses (mainly taste and smell but also sight and touch). So the idea is to use the sensory analysis tools, adapted to the partners' fields and products.

4.1. Sensory analysis : application to manufactured product

In the food industry, sensory analysis is used to classified products depending on a well defined criterion to emit a personal judgment often independent of experimentation conditions. The different methods proposed in literature [12, 16] highlight the different kind of classification scale and present the most efficient comparison processes. One example of the food industry problematic: a study consists of classifying biscuit depending on his perceived sugar rate [16]. In this kind of studies, it is known that the test morphology: scale used (free or structured) and the product-presentation-order influences the results. Or this kind of influences is harmful in the case of industrial manufactured products.

A good aspect of the sensory analysis method as it is applied in food industry is the metrological structure. This structure is composed of experts who define the evaluation criterion, the acceptance limits, and they set up the references and the control morphology (as we described previously). This structure is useful to set up the experimentation objectives and deduce the conditions (time, tools, light) permitting to access to the mandatory information for the evaluation. Moreover, formation, calibration and accompaniment are necessary to make sure the controllers use the tools correctly.

4.2. Split the concepts : detection, evaluation and decision

A previous study [5] realised in a luxury watch making company permitted to evaluate the sensory analysis tools relevance applied in the context of manufacture product. This study shows in particular the interest of separating the three concepts of visual control: anomaly detection, evaluation of perceived anomaly (work on descriptors) and final acceptance decision.

A good control comes from a good vision

To detect correctly, it is necessary to know « what » to see. It is proved that visual attention permit to increase the concentration level and the performances of visual detection (in particular the contrast perception) [17]. That is why it is important to identify the possible anomalies we want to detect on the product. Of course those possible anomalies depend on the product, the fabrication process… (Even within a firm). Defining anomalies' characteristics and properties is necessary to use the right tools and method to be able to detect. To share this definition of anomalies, it is necessary to use a common vocabulary.

The definition and identification of anomalies is the first step. The next step is the control-process standardisation by procedures specifying:

- Necessary skills (vision accuracy, colour detection, common vocabulary…)
- Tools to be used (flunks, light…)

- Product, body and eyes movements

This standardisation helps the controller to be exhaustive during the detection task and permit the access to information permitting the evaluation task. It also permits to reduce practices variability during the detection.

A good evaluation comes from quantification and discrimination

The evaluation step consists on quantifying the visual impact of the detected anomalies. This visual impact is not measurable so the quantification is not easy. However it is possible to know the discriminating properties thanks to anomaly definition. For example a small stripe (small geometrical dimensions) on a black piece will have a worst visual impact than a big stripe on a white piece. So the geometrical properties are not discriminating. Finding those properties is part of the whole project.

The quantification is an important step to associate a magnitude level to the visual impact of each anomaly. Panoplies are often used as a quantification scale. But part of the method is to give a common meaning to some word to be able to set this quantification without references. Finding factual evaluation criterion is one important objective of the project. Those criterions could be based on anomaly visibility properties: which conditions are necessary for me to perceive the anomaly.

The work on detection helping tools permits to see more details and more anomalies faster than before. But more anomalies do not mean more defects. We thus noticed the importance of the evaluation step which allows us to make the difference between anomalies (acceptable) and defects (non acceptable).

A good decision takes into account all parameters

The decision step is the last one, and gives the final answer about the product conformity. The anomaly localisation is essential to determine its criticality. The decision, as in the dimensional metrology depends on tolerances fixed by the expert group (often integrating the marketing decisions). The same gap between the reference surface and the real surface does not have the same visual impact depending on its location. Actually the localisation analysis permits to evaluate the risk for the customer to see the anomaly. Thus, the most visible zones are considered as the most critical.

Finally the decision step consists on putting together results from each step:

- Detection: which anomaly
- Evaluation: which visual impact
- Localisation: where stand the anomaly

The decision, as it is build permits to emit an objective judgement about the conformity based on subjective data from the previous steps.

Finally, some concepts used in food industry are suitable to be used to control manufactured products. The difference between emitting a personal judgement (sensory analysis) and an objective evaluation based on defined criterion impose an evolution of the evaluation tools. So the tools should allow more than a comparison, an evaluation based on common references, criterions and acceptance limits fixed by the expert group.

5. GENERAL CONCLUSION

In this study we noticed that the lack of specification, recommendation or even referent studies about visual control, each firms developed its own practices and tools. We noticed a great variability of those practices. So we noticed two different variability sources: the intern variability, the people’s practices variations within a firm and the extern variation which defines the practices variability between several firms.

The first answer of this study is to reduce the intern variability by the definition of control environment and the second one is to set up a generic method suitable for every fields and firms. So in several firms we are setting up a new kind of control procedures, specifying the control task. Those procedures take into account the fabrication process and the risk to create one anomaly in particular to specify what to detect. In addition to get the control easier and more efficient, most of the new procedures impose an eyes course and the amount of time for the task. To control and reduce the environment variability, we are working on the illumination conditions. Several light sources configurations are studied to find the best conditions independent from the natural light sources.

The approach needs the creation of the metrological structure. It is composed of a representative anomaly panel, an expert group emitting the “right” judgement and a formation an evaluation of measurement tool (the controllers). In every firm this group of expert has been created, and a panoply illustrating the most significant defects is being created. The next step is to create a tool illustrating the decisions taken by the expert group. To set up this tool we need to know the criterion of each expert and make them agree about the “generic criterion” to be understood and shared by everyone.

Finally, one of the most important points is to split the control along the three visual control concepts. The detection step impose to control the observation conditions, to evaluation correctly, a definition of shared evaluation criterion is mandatory and the definition of acceptance limits and critical zones in the product permit to take the right decision automatically.

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